The Gravity Recovery and Interior Laboratory (GRAIL) Mission

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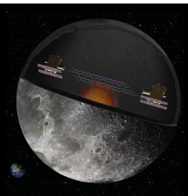

GRAIL science objectives

Mariner 10

- Primary:
  - Determine the structure of the lunar interior, from crust to core
  - Advance understanding of the thermal evolution of the Moon
- Secondary:
  - Extend knowledge gained from the Moon to other terrestrial planets

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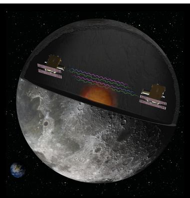
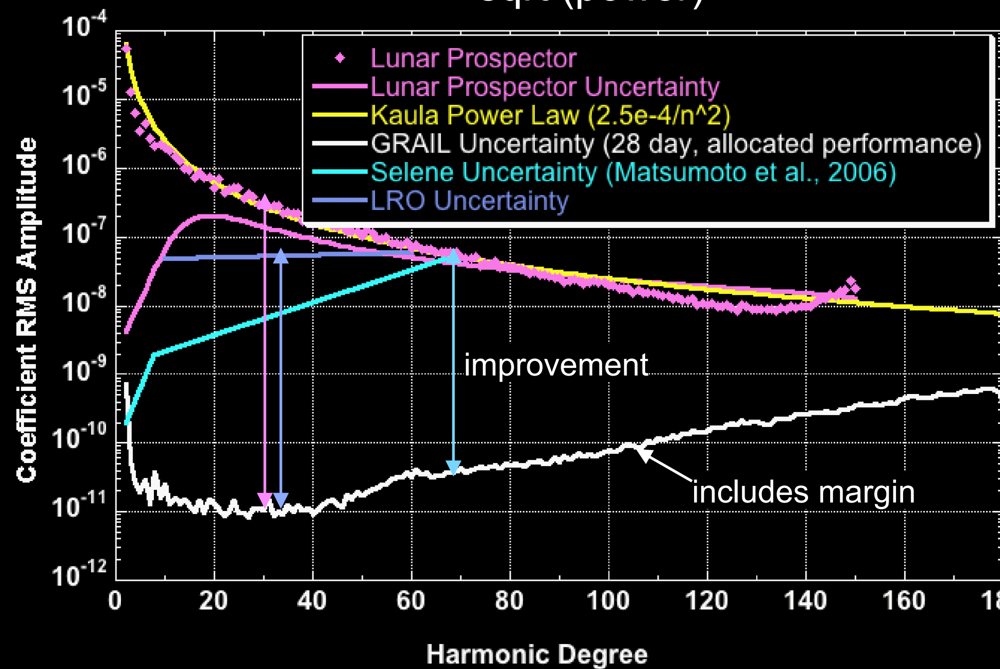


GRAIL performance

Recent/Anticipated Lunar Gravity Missions

Reference	Data	Comment
Lemoine et al. [1997]	Lunar Orbiter 1-5, Apollo subsatellites, Clementine	70°x70° (78 km) spherical harmonic solution
Konopliv et al. [2001]	Lunar Orbiter 1-5, Apollo sub-satellites, Clementine, Lunar Prospector	~130°x130° (42 km) nearside, 15°x15° (365 km) farside w/ amplitudes suspect; weak k_2 estimate
KAGUYA (SELENE; 2007; Japan) subsatellite	S- and X-band; 70°x70° (80 km x 80 km) spherical harmonic solution	Data noise more than 100x > GRAIL; spatial resolution 4x coarser than GRAIL.
Lunar Reconnaissance Orbiter (2008; USA)	S-band; laser tracking to s/c on nearside	Improvement to 1-m radial s/c orbits; best effort gravity field. Data noise more than 100x > GRAIL
Gravity Recovery and Interior Laboratory (GRAIL)	Satellite-to-satellite tracking (Ka-band); S-band link to Earth	Global 180°x180° spherical harmonic solution (30 km x 30 km); k_2 to 1%

sqrt (power)



- GRAIL gravity field to l=270 (block size 20 km)
- KAGUYA gravity field to l=70 (block size 80 km)
- @ l=70, KAGUYA S/N =1; GRAIL S/N = 1000

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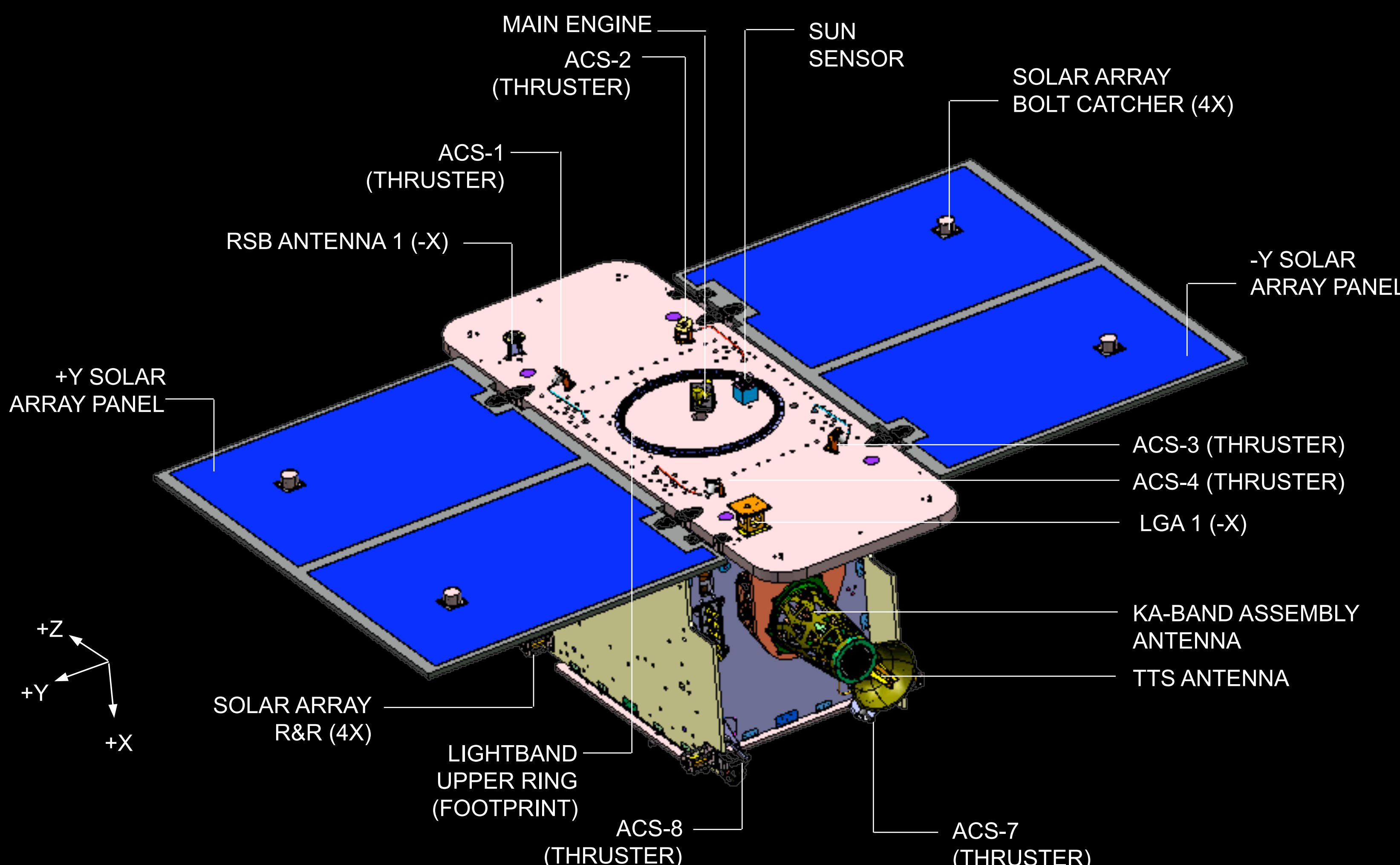
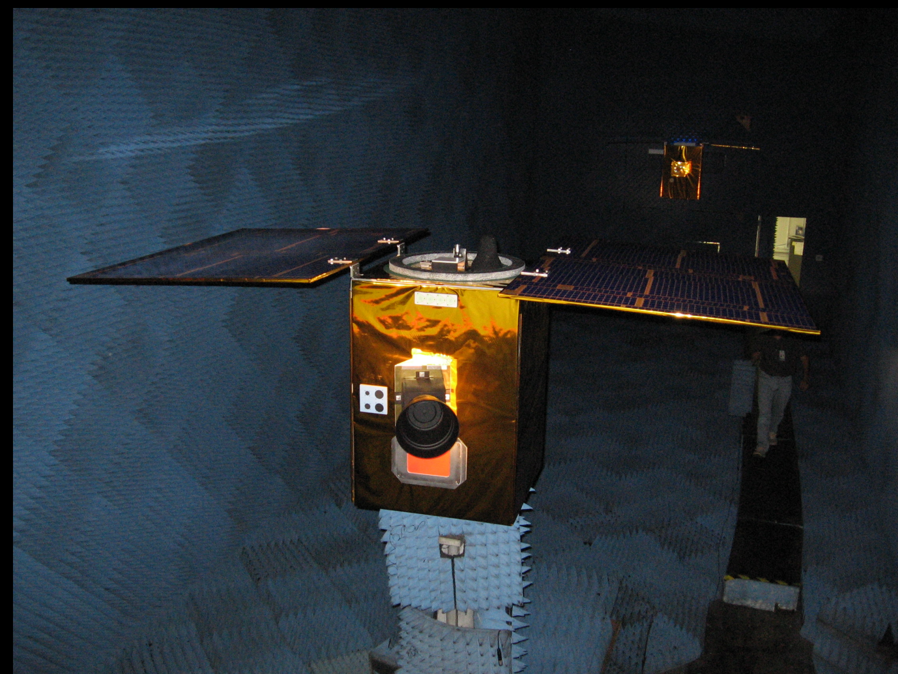
GRAIL Orbiter Configuration

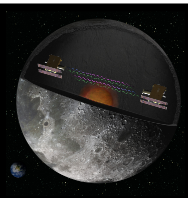


Gravity Recovery Instrument for Planets (GRIP)

- GRAIL payload prototype demonstrated and *exceeded* required mission performance.
- Capability to change line-of-sight distance in sub-micron steps.
- GRAIL terminal and GRACE spare terminal ranged using GRACE software demonstrated inter-operability of hardware and software.
- Test bed being used for performance testing of flight hardware and software.



JPL/Caltech



GRAIL's science investigations

1. Structure of lunar crust and lithosphere
2. Asymmetric thermal evolution
3. Subsurface structure of impact basins and origin of mascons
4. Temporal evolution of crustal brecciation and magmatism

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5. Interior structure from lunar tides
6. Constraints on whether Moon has an inner core

Science Floor

Baseline

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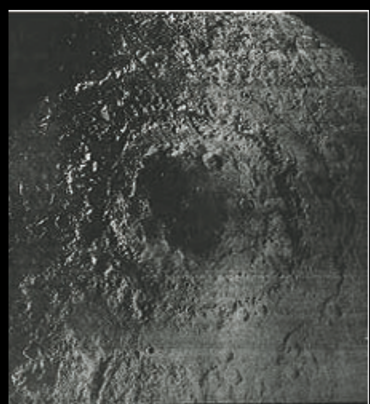
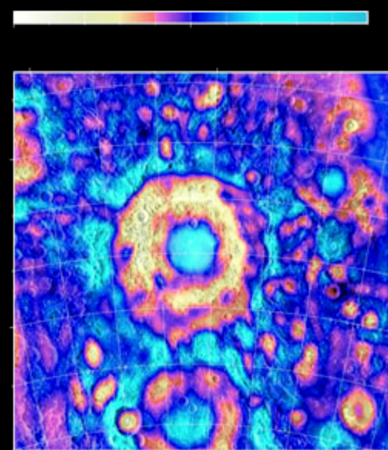
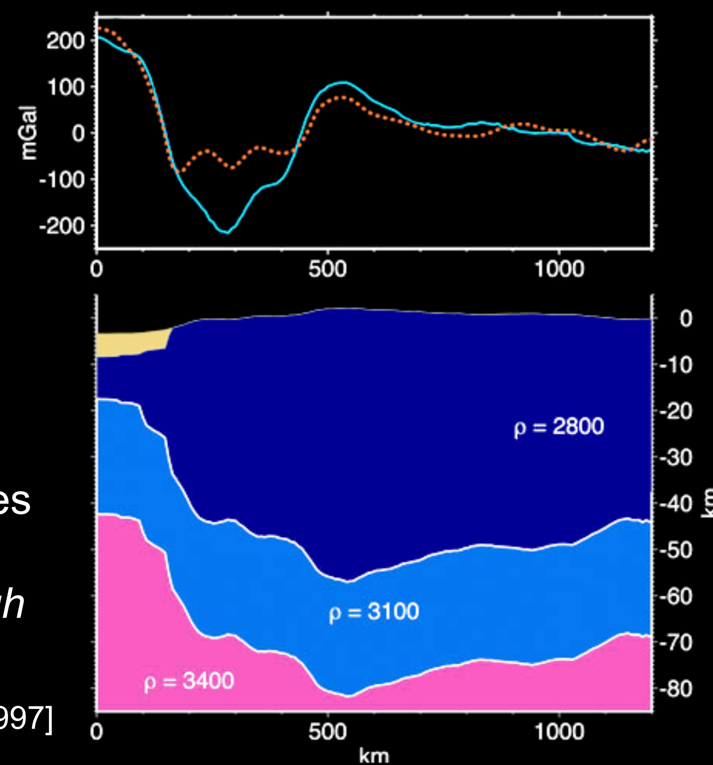
Early cooling indicated by structure of impact basins







It is enigmatic that lunar lithosphere apparently was able to support such large gravity anomalies during & after late heavy bombardment.

➔ *Early lunar lithosphere cooled quickly enough to support large loads.*

Neumann et al. [1996]; Wieczorek and Phillips [1997]

Orientale Basin: Oblique view of Orientale along with gravity from Model LP150Q. Panels (right) show gravity predicted by flexural model with T_e = 50 km assuming a dual-layered crust (dark & light blue).

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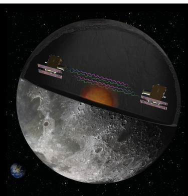
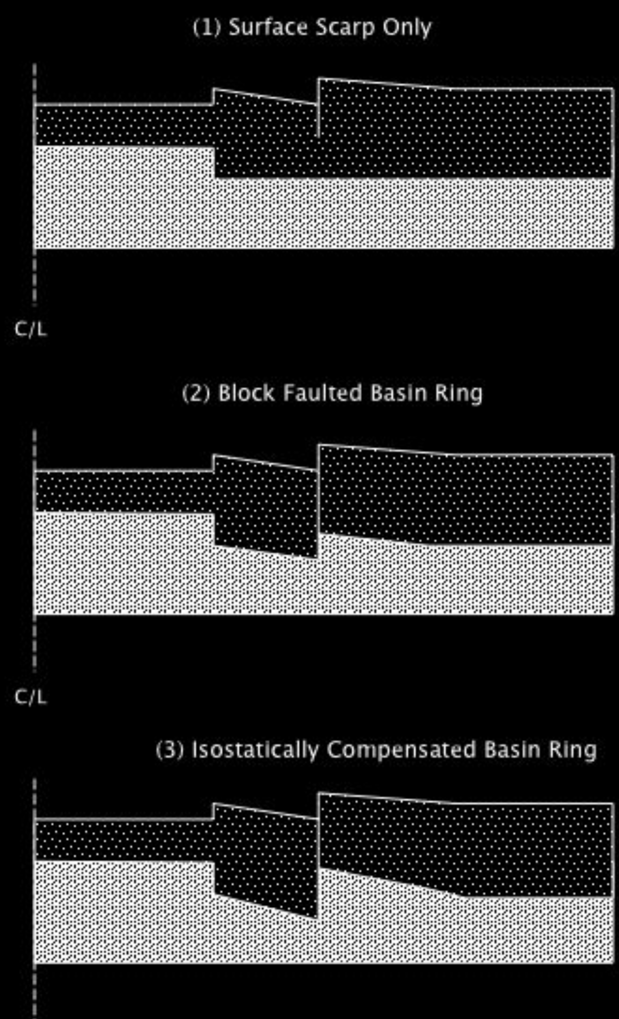
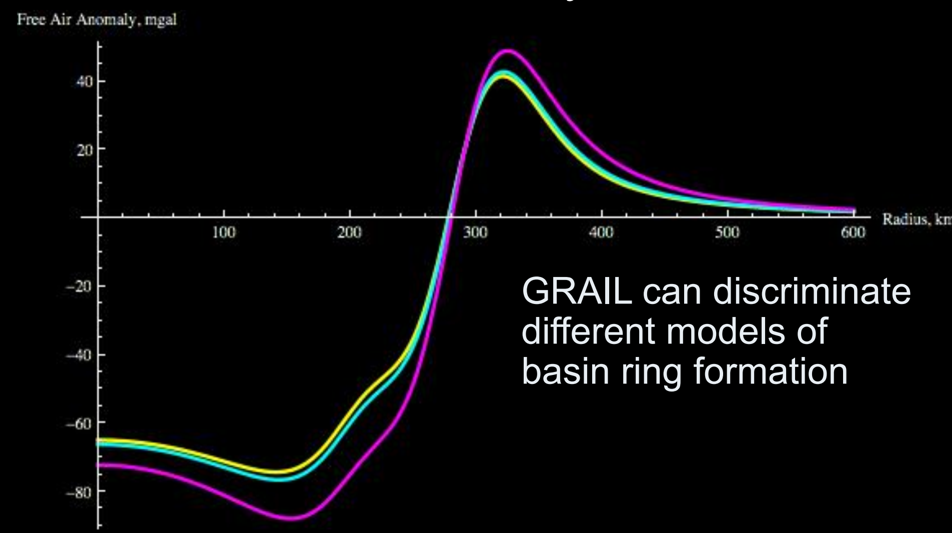


Basin Ring Formation

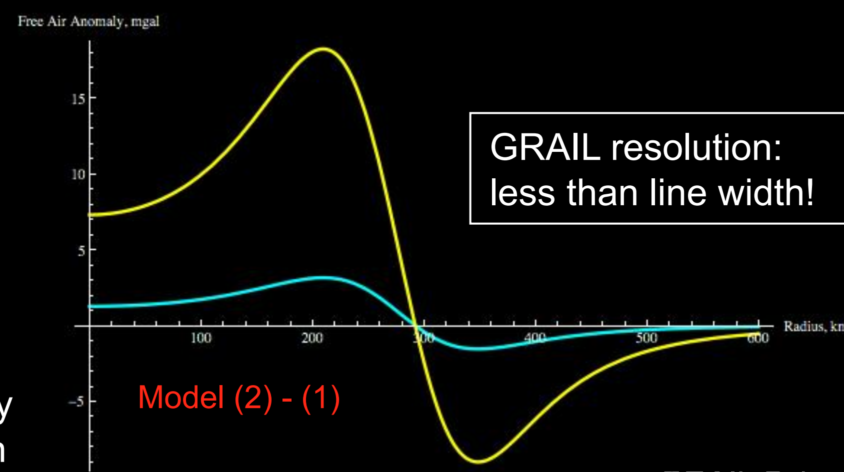


Total Free-Air Gravity Anomalies



GRAIL can discriminate different models of basin ring formation

Differential Anomalies



GRAIL resolution: less than line width!

Orientale Model: Basin diameter = 400 km, Crust density = 2900 kg/m^3, Mantle density = 3900 kg/m^3, Basin depth = 3 km, Scarp height= 6 km, Crust thickness = 50 km.

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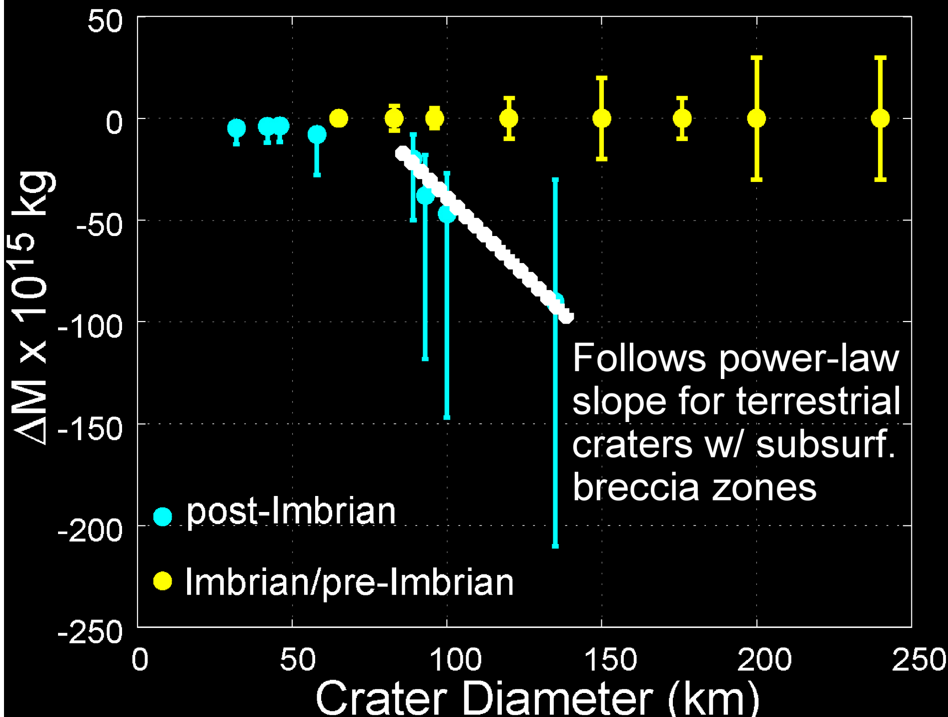
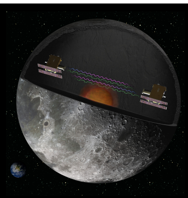
Magmatism and Brecciation



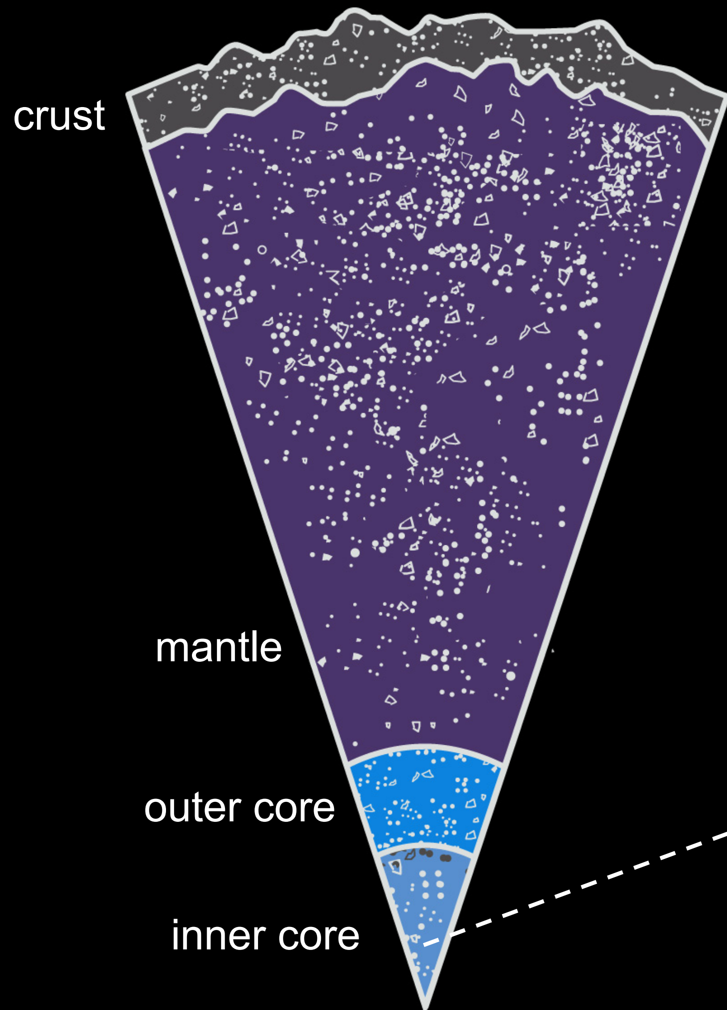
- Apollo-era gravity analysis of 16 lunar craters. Post-Imbrian craters show mass deficiency in subsurface, whereas older, unfilled craters show ~zero mass deficiency.
- Hypothesis is that craters formed w/ breccia zones that were magmatically sealed during Moon's volcanic era.
- Analysis was hampered by small data set & errors in gravity & topography.

Bouguer LOS gravity was calculated for 8 post-Imbrian craters & 8 older, unfilled craters & converted to mass anomalies. LOS free-air gravity was obtained from Doppler tracking data from Apollo 14-17 CSMs, A16 LEM, and A15-16 sub-satellites. S/C altitude ranged from 15 to 80 km. Topography from Apollo LTOs & (mainly) Earth-based radar. From Dvorak [1979].

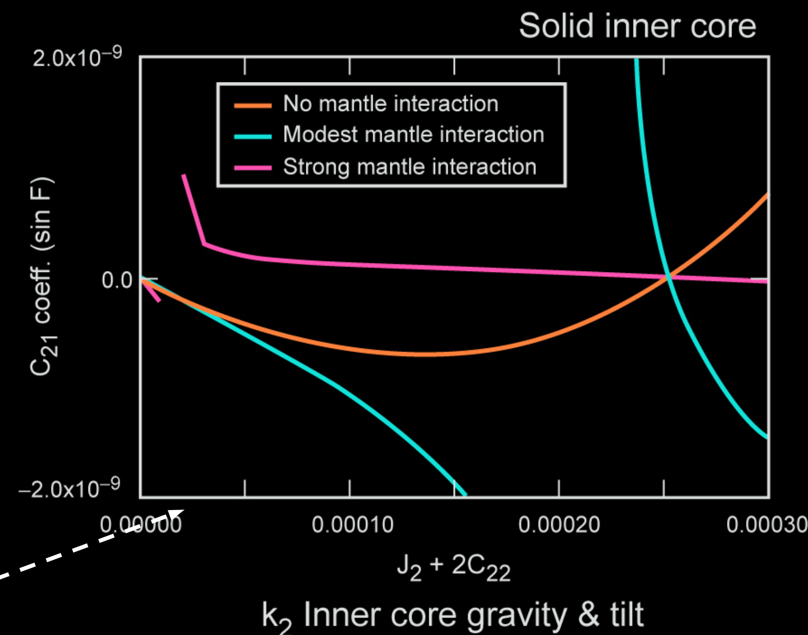
GRAIL can test this hypothesis, including role of compensation, with a global high-resolution, high precision data set, and, if valid, can map out magmatic history of lunar crust in space and time.



Deep interior: Inner core detection



J_2 = gravitational oblateness
C_{22} = gravitational shape of equator
C_{21} = measures how gravity field is aligned with respect to polar axis of coordinate system



Williams [2007]

Tradeoff between inner core gravity and tilt required to detect solid inner core.

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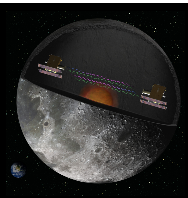

Science requirements and system performance

Science Investigations	Area (10^6 km^2)	Resolution (km)	Requirements (30 km block)	Baseline Performance (CBE) 90 days
1. Crust & Lithosphere	~10	30	± 10 mGals, accuracy	± 1.0 **(0.2) mGals**
2. Thermal Evolution	~4	30	± 2 mGals, accuracy	± 1 **(0.2) mGals**
3. Impact Basins	~1	30	± 0.5 mGals, precision	± 0.2 **(0.04)mGals**
4. Magmatism	~0.1	30	± 0.1 mGals, precision	± 0.04 **(0.007) mGals**
5. Deep Interior	N/A	N/A	k2 ± $6x10^{-4}$ (3%)	± 0.5 **(0.3) $x10^{-4}$**
6. Core Detection (Inner)	N/A	N/A	k2 ± $2x10^{-4}$ (1%)	± 0.5 **(0.3)$x10^{-4}$**
			C21 ±$1x10^{-10}$	± 0.5 **(0.3) $x10^{-10}$**

90-day mission Current Best Estimate (CBE) Performance meets science requirements with considerable margin.

GRAIL Programmatic Summary

- Level 1-4 requirements defined; Project Level Rrquirement Appendix signed.
- Passed Preliminary System Review (04/08)
- Passed 15 inheritance reviews
- Passed 19 subsystem PDRs
- Fully compliant with NPR 7120.5D
- All required documents and schedules delivered
- Successful Preliminary Design Review (11/11-11/14); asked by SRB to study accelerating CDR by as much as 6 weeks given current state of Project maturity.
- Passed Confirmation Review (01/20/09)
- Critical Design Review scheduled for 11/09
- *GRAIL is currently on cost, on schedule, and within all required margins for mass, power, etc.*

http://grail.mit.edu/